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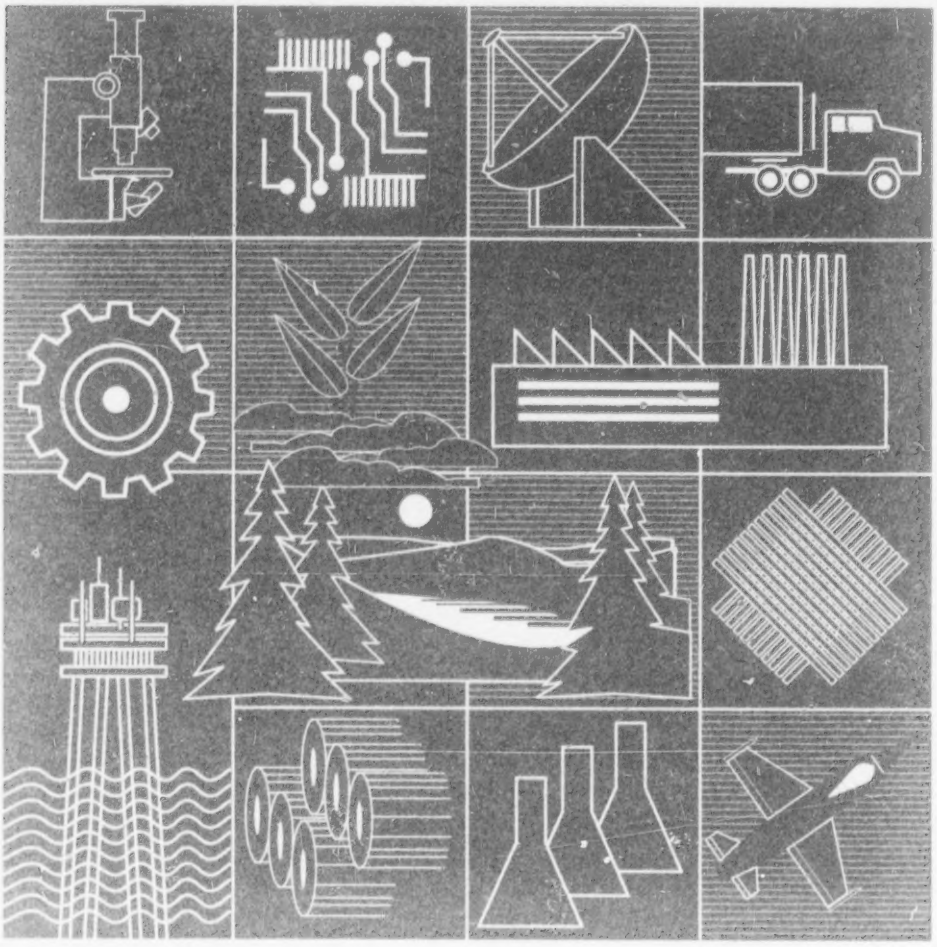
BATTELLE'S R&D FORECAST



Probable Levels of R&D Expenditures in 1992 Forecast & Analysis

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This Battelle report is based upon a continuing study of U.S. expenditures for research and development. It was prepared by Drs. Jules J. Duga and W. Halder Fisher of Battelle Columbus Operations. Parts of the data presented here were derived from such sources as the National Science Foundation, published R&D data, and others.

December 1991.

PROBABLE LEVELS OF R&D EXPENDITURES IN 1992

SUMMARY OF FINDINGS

1. Total U.S. expenditures for R&D will be $155.9 billion in 1992—a 2.86 percent increase over the $151.6 billion that the National Science Foundation (NSF) estimates will have been spent in 1991.

2. Costs to perform R&D will rise approximately 2.0 percent from 1991 to a 1992 index level of 140.97 (1982 = 100 percent), absorbing a portion of increased funding. This implies a real increase in expenditures of approximately 1.0 percent, reaching a new peak in total real funding of R&D (Figure 3).

3. Federal government funding in 1992 will be about $67.6 billion (43.3 percent of total), an increase of $1.6 billion (2.4 percent) over 1991. R&D performed by the federal government will represent $16.8 billion (10.8 percent), an increase of less than $400 million (2.2 percent) over 1991 estimates.

4. Industrial funding in 1992 is expected to be nearly $80.6 billion (51.7 percent of total), an increase of $2.5 billion (3.2 percent) over 1991. R&D performed by industry is expected to rise to $111.5 billion (71.5 percent of total), an increase of $3.1 billion (2.8 percent) over 1991.

5. The federal government will support the industrial sector's anticipated total performance by approximately 30 percent—a figure less than the nearly 34 percent essentially constant over the past decade.

6. Academic and other nonprofit institutions will fund $7.8 billion of R&D in 1992 (4.5 percent of total) and will perform over $27.6 billion (about 17.7 percent). These figures represent increases in the percentage of support and performance over the 1991 NSF estimates and include the federal support to Federally Funded Research and Development Centers which are managed by individual universities or consortia.

7. In the nonprofit category, colleges and universities will account for 63.3 percent of the 1992 funding and 82.0 percent of the R&D performance. Both of these figures are comparable with the ratios derived from the 1991 NSF estimates.

8. Historically, costs of R&D have risen steadily in all four categories (federal, industrial, colleges and universities, and other nonprofits), and are driven by overall inflation, a so-called sophistication factor, and the general nature of research programs.

9. The trend in real R&D effort (see Figure 3) continues to rise, as it has over much of the past decade. Battelle estimates that the real growth of R&D will continue to decline over the next few years, but that significant increases will again occur in the latter half of the decade.

10. Significant factors influencing trends in support and performance of R&D include:

- **Federal government emphasis on defense programs** will be felt primarily in the aerospace, electronics, and communications industries, but the rate of growth is expected to show continued decline and a possible turnaround during 1992.
- **Energy-related R&D programs** will continue to experience mixed federal support. Although some of the so-called big science programs have not had the anticipated level of continuing support, early indications are that even these will find greater favor in 1992, continuing into 1993.
- **University self-funded programs** are likely to continue growth, although their rate of growth may not be sustained over the near term.
- **The peace dividend,** highly touted following the political, economic, and military changes in Eastern Europe, will have less impact on research than on overall military procurement. However, pressures faced by the federal budget, and concern over real business recession will temper the total rate of R&D growth and, perhaps, even lead to short-term downturn in real R&D expenditures.

11. As a continuing feature, this report provides a preliminary forecast of R&D funding levels in 1993. As a result of significant uncertainties relative to general business considerations, the preliminary 1993 forecast is based upon three different near-term scenarios.

12. These types of statistics and surveys—even with their inherent inaccuracies—are sufficient for broad analyses of U.S. R&D trends; however, much more detailed work will be required if R&D analyses are to be more useful for defining competitive postures, both for individual industries and for the nation as a whole.

13. In addition to continued support for R&D, industry will expand its emphasis on developing and implementing means to assess the long-term impact of technological and intellectual resources.

ANALYSIS AND FORECAST

Since research and development (R&D)* and the applications of technology are our prime concerns, Battelle is interested both in forecasting R&D expenditures and in assessing the cumulative results of R&D activities—technological, economic, and social. Accordingly, Battelle performs a continuing study of forces affecting R&D activities and sources of support. The tangible products of this research include a series of annual analyses and forecasts of R&D expenditures. This report represents the latest in that series.

This report's content has evolved to supply information Battelle considers useful to the R&D community, but not adequately supplied by two well-known and respected series of reports: the National Science Foundation's *National Patterns of Science and Technology Resources* and the DRI/McGraw-Hill *Annual Survey of Business Plans for R&D*.

In earlier years, NSF *Patterns* was published during the first half of each year (usually in April) and included a forecast of that same full year's R&D expenditures by source of funds and by performer. More recently, *Patterns* contained both preliminary data for the closing fiscal year and estimates for two preceding years. Recently, *Patterns* has been published late in the calendar year, and contains better estimates of the R&D funding and performance for that same year.

Budget constraints and employment freezes at NSF have taken their toll on the *Patterns* report and the supporting activities throughout the NSF Division of Science Resource Studies. The effects of these cutbacks have been felt not only by continuing private-sector users of NSF data but also by policy makers and analysts within the federal government. Furthermore, these same budget cutbacks have resulted in the possibility that *Patterns* will only be published on a biannual basis (although some of the data will be available), thus adding more complications for both private- and public-sector users of this valuable resource.

As an additional complication, NSF data have always had a degree of uncertainty, especially as related to recent years' histories. Each year, the NSF data on previous years (sometimes as far back as 10 years) have been subject to corrections. For example, some of the 1986 data reported in 1991 are different from the 1986 data published in 1990. These adjustments thus present problems in consistency between forecasts made in different years. The lack of background data and their interpretation can only have a negative impact on those agencies concerned with the strength of the U.S. R&D effort and the policy measures implemented to ensure competitive postures.

The DRI/McGraw-Hill surveys (usually published at about the same time as the earlier issues of *Patterns*) made forecasts—the 1989 Survey (published in June) made forecasts for 1989 and 1992—but are confined to the overall performance of broad industrial sectors, some of which are not well defined and delineated, and do not separate federal government from industrial funding. These surveys, coupled with the R&D Scoreboard, formerly published in midyear by *Business Week*, are instructive to the extent that they provide generalized patterns and trends. However, as will also be shown in later discussions (see "The Need for Better Data"), they fell far short of providing a complete tool for detailed analysis, evaluation, or planning. Furthermore, DRI has ceased this aspect of their survey work, thus creating a significant void in the literature.

Starting with the 1980 Forecast, we have included a forecast of industrial R&D expenditures according to broad industry class, along with the estimated distribution of those funds between industrial and federal sources. This added feature provides the background necessary for understanding the way federal policy can affect industrial innovation, spur industrial support of its own R&D efforts, and enhance the long-term international competitiveness of U.S. industry.

However, we have been forced to temporarily suspend the detail on industrially performed R&D due to the absence of DRI's primary data collection activity. We are exploring other means to meet this need and expect this void will be filled in the future.

Continuing the practice initiated in the 1984 Forecast, we present estimates which cover a two-year forecast to 1993.

Historical Trends in R&D Funding and Performance

Although the NSF data series began in 1953, we begin our analysis with 1960 data. Even that year represents ancient history so far as the forces currently affecting R&D are concerned. The NSF data from 1960 through 1991 are shown in Table 1. It is instructive to include this early history for there are some features, as described later, which are parallel to those that are observed today and into the near future.

In 1960, NSF surveys indicated that approximately 64.6 percent of all R&D-supportive funds were provided by the federal government, 33.4 percent were provided by industry, and 1 percent each came from the academic community and from other nonprofit organizations. Between then and the present, federal funding rose to 66.5 percent in 1964, but generally slowly declined to 43.5 percent in 1991. Over that same period,

* The National Science Foundation's definitions of R&D are given in the Technical Appendix to this report.

Table 1.
Sources of R&D Funds and Performers of R&D, United States, Calendar Years 1960–1991 (Millions of Current Dollars)

Year	Total R&D	Sources of Funds: Federal Gov't.	Industry	Colleges and Universities[b]	Other Nonprofit[c]	Performance[a]: Federal Gov't.	Industry	Colleges and Universities[b]	Other Nonprofit[c]
1960	13,523	8,738	4,516	149	120	1,726	10,509	1,006	282
1961	14,316	9,250	4,757	165	144	1,874	10,908	1,173	361
1962	15,394	9,911	5,123	185	175	2,098	11,464	1,374	458
1963	17,059	11,204	5,456	207	192	2,279	12,630	1,611	539
1964	18,854	12,537	5,887	235	195	2,838	13,512	1,904	600
1965	20,044	13,012	6,548	267	217	3,093	14,185	2,103	663
1966	21,846	13,968	7,328	304	246	3,220	15,548	2,345	733
1967	23,146	14,395	8,142	345	264	3,396	16,385	2,594	771
1968	24,605	14,928	9,005	390	282	3,494	17,429	2,868	814
1969	25,631	14,895	10,010	420	306	3,503	18,308	2,950	870
1970	26,134	14,892	10,444	461	337	4,079	18,067	3,072	916
1971	26,676	14,964	10,822	529	361	4,228	18,320	3,216	912
1972	28,477	15,808	11,710	574	385	4,590	19,552	3,383	952
1973	30,718	16,399	13,293	613	413	4,762	21,249	3,701	1,006
1974	32,864	16,850	14,878	677	459	4,911	22,887	3,888	1,178
1975	35,213	18,109	15,820	749	535	5,354	24,187	4,396	1,276
1976	39,019	19,914	17,694	810	601	5,769	26,997	4,877	1,376
1977	42,783	21,594	19,629	888	672	6,012	29,825	5,451	1,495
1978	48,128	23,875	22,450	1,037	766	6,810	33,304	6,342	1,672
1979	54,953	26,825	26,082	1,214	832	7,418	38,226	7,315	1,994
1980	62,610	29,461	30,912	1,334	903	7,632	44,505	8,323	2,150
1981	71,868	33,409	35,944	1,554	961	8,426	51,810	9,332	2,300
1982	80,018	36,578	40,692	1,731	1,017	9,141	58,650	9,802	2,425
1983	89,139	40,832	45,251	1,929	1,127	10,582	65,268	10,614	2,675
1984	101,139	45,641	52,204	2,104	1,190	11,572	74,800	11,767	3,000
1985	113,818	52,120	57,977	2,376	1,345	12,945	84,239	13,209	3,425
1986	119,529	54,273	61,056	2,790	1,410	13,535	87,823	14,821	3,350
1987	125,352	57,904	62,642	3,200	1,606	13,413	92,155	16,359	3,425
1988	133,741	61,499	66,953	3,473	1,816	14,281	97,889	17,996	3,575
1989	140,486	62,688	71,767	3,948	2,083	15,121	101,599	19,716	4,050
1990	145,450	64,000	74,700	4,450	2,300	16,100	104,200	20,800	4,350
1991	151,600	66,000	78,050	4,950	2,600	16,400	108,450	22,050	4,700

Source: National Science Foundation.
(a) The R&D performance of Associated Federally Funded Research & Development Centers (some administered by industry, some by colleges and universities, and some by other nonprofit organizations) has been combined with that of the administering institutions.
(b) As sources of funds, these include state and local government funding.
(c) All other nonprofit institutions.

industrial funding declined to 31.2 percent in 1964 and rose to 51.6 percent in 1984, with a small decline and rise thereafter. Since 1964, the percentage of total funding by colleges and universities rose steadily to a value between 2.0 and 2.3 percent of total funding. This level of funding remained constant for over a decade and a half, and then suddenly, since 1985, increased to as high as 3.3 percent in recent years. Other nonprofit funding reached a high of approximately 1.6 percent of the total in 1978, and has exhibited a slow decline and resurgence in the past decade. The apparent growth in college and university funding is partially ascribable to the more detailed bookkeeping methods that are used to account for this sector's sources of funds.

Through 1982, trends showed a continued increase in industrial funding as a percent of total funding, with a corresponding decrease in the proportion of federal-sector funding. In the mid-1980s, the relative contributions by industry and the federal government remained essentially constant. This was largely due to significant increases in defense spending, industrial response to a healthier economy, and other initiatives (see the later discussions on the role of industry). Recently we have seen a small, though significant, widening of the gulf, with federal spending declining as a percent of the total.

Although the federal government was the major *source* of R&D funds from 1953 through 1979, industry has been the dominant R&D funder since 1981. Industry is by far the major *performer* of R&D. Federal performance of R&D rose from 12.8 percent in 1960 to 16.1 percent in 1972. It has been decreasing since that year and has fluctuated around the 11.0 percent mark since 1980. Industrial performance reached a high point of 79 percent in 1957 and drifted steadily downward to a low of 68.6 percent in the early 1970s. More recent trends suggest a slow increase in the proportion of industrial performance, which has risen to over 73 percent and has maintained nearly that share over the past eight years, albeit with slight recent declines.

While the academic community's performance varied between 6 and 8 percent before 1960, there has been a slow but steady increase in the percentage of R&D performed in this sector, with recent levels reaching 14 percent. This total includes the R&D performed at the university-managed Federally Funded Research and Development Centers (FFRDCs). Since the early 1980s, this sector's share of performance has been in slight decline, although there has been a reversal of this trend in the past six years. Such a reversal resulted in part from industrial initiatives.

For most of 1960–1980, other nonprofit organizations increased their share of R&D performance from 2 to about 3.6 percent of the total. However, that share decreased steadily in the past decade, and has only recently shown a slow growth.

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It should be noted that federal funding supports research performed by all sectors. Currently, almost one-fourth of federal R&D funding supports intramural R&D; slightly less than one-half supports industry; a little more than one-fifth supports colleges and universities (through direct grants and contracts, as well as through the FFRDCs); and the rest, slightly over 4 percent, supports other nonprofit organizations. Industry absorbs almost all of its own funding, either intramurally or by contracting with other industrial performers. Its contracts and grants to colleges and universities exceed those to other nonprofit institutions by a factor of two. Other nonprofits finance both themselves and academic institutions about equally, while colleges and universities absorb all the funds they originate.

In Table 1 we summarize the latest NSF time series on the sources of R&D funding and the volumes of R&D performance. During the interval since 1960, total R&D dollars (not adjusted for inflation) have increased more than elevenfold. Federal funding has multiplied by a factor of 7.6 and federal performance has increased by a factor of 9.5. In terms of constant dollars, total R&D expenditures have increased by a factor of over 2.3 from 1960 to 1991.

Also noteworthy is the high ratio of academic performance to academic funding. In the later years of this period, colleges and universities have provided about one-sixth of the total support for their own R&D activity, with much of the remainder (about 90 percent) coming primarily from the federal government. Recently, this ratio has tended to decrease, not only as a result of some reduction in selected federal programs but also because of an increase in academic funding. As suggested earlier, this latter is largely a bookkeeping artifact created by the manner in which university funds are ascribed to universities, rather than to the ultimate original sources.

Beginning in 1968, there was a distinct change in the rate of growth in R&D, triggered by a leveling in current-dollar federal funding. This phase seems to have ended in 1971, when current-dollar expenditures resumed an accelerating growth trend more nearly like that prior to 1968. As anticipated in the last three Battelle Forecasts, there is continued growth of total real R&D support, although the rate of growth has slowed. Present trends even suggest that the total real R&D support could go through a short-term reversal. Whether this will happen will depend upon a number of factors to be elaborated upon later in this report.

The continuing transition in R&D support and performance has had significant impact on patterns within the overall R&D enterprise. In addition to changes in energy and social service R&D programs, there have been changes in the structure of federally supported R&D. In particular, budgets for basic research—much of which is directed ultimately toward defense applications—had shown a steady increase, growing at a rate of about 8 percent per year (in current dollars). However, as a percent of total federal R&D dollars, budgets for basic research have been declining in recent years.*

One must note, however, that the federal government's posture toward basic research—especially that associated with the so-called big science programs—continues to expand. The federal government continues to provide strong support for basic research, although increases in some big-ticket items do not keep pace with inflation. As we move through 1992, the overall emphasis on research will be couched in terms of international competitiveness, the support of research which forms the basis for future economic strength, and the need to continuously define and support work in the so-called critical technologies. It is expected that such emphasis will be more than merely political rhetoric that is characteristic of a campaign year: it will be a statement of the continuing commitment to advancement of science, although none of the major candidates will be able to focus on the means for translating that science into real economic progress. To do so would open the debate into one of overt "industrial policy," a theme that has been judiciously avoided by all parties for many years.

*One must use caution, however, in attempting to draw too many conclusions based upon the most readily available statistics. Two problems arise: (1) the demarcation between "basic research" and "applied research" as well as that between "applied research" and "development," is not uniformly applied; and (2) the actual detailed surveys are not sufficiently accurate, reproducible, or recent to provide much confidence in the details.

The federal government will continue to move away from the support of research that is of a more applied and development nature, especially when it is related to industrial applications where near-term commercialization is expected. On the other hand, support is expected to continue in generic technologies that have direct benefit to government and industry alike, such as in computer-aided design and manufacturing, the development of logistics-support software, and a continuing effort in high-risk basic research in the health-related fields.

Finally, the federal government will continue to support programs that deal with the environment—including the prevention, identification, and amelioration of threats to air, water, and land quality—and will promote other programs that contribute directly to economic growth.

As will be discussed in greater detail later, 1992 is expected to begin a long-term trend in modifications of the federal budget and the priorities that are reflected therein. For the past few years, there has been the anticipation of a so-called peace dividend resulting from improved relations between the U.S. and the former Soviet Union. Significant accords have been attained, and all indications point toward a major decrease in federal defense expenditures. Even as plans are being considered for changes in the total defense budget, there are no indications that the R&D portion of that budget will be subject to concomitant reductions.

Events of the past year have underscored the anticipation of major—though perhaps slow—changes in the federal R&D posture. The stunning success of the U.S. and allied forces in the Middle East demonstrated the manner in which local or regional conflicts may be addressed by high-technology weaponry. The total political collapse of the Soviet Union has removed a major organized potential adversary from the list of those who may be considered as significant military threats. And opening potential markets in Eastern Europe has raised the potential that a totally different type of R&D will be forthcoming, a field that could be considered as "culturally adoptive R&D"—that research which is required in order to make processes and products fit better into the buying habits, usages, needs, and regulatory environments which exist.

These are themes that underlie the future directions of both government- and industry-sponsored research, and will likely influence both the direction and extent of R&D expenditures for the next several years.

Forecast for 1992

During calendar year 1992, Battelle expects the total current dollar volume of R&D activity to be higher than the 1991 level estimated by NSF. A comparison of Battelle's 1992 forecast with the last available NSF estimates for 1991 is shown in Table 2. The 1992

Table 2.
Estimated R&D Expenditures by Source of Funds and by Performers, U.S. Calendar Years 1991 and 1992 (Millions of Current Dollars)

	Performer				Source Totals	
Source of Funds	Federal Government	Industry	Colleges and Universities	Other Nonprofit	Dollars	Percent of All Funds
			1991 NSF ESTIMATES			
Federal Government	16,400	32,300	14,500	2,800	66,000	43.54
Industry	—	76,150	1,250	650	78,050	51.48
Colleges & Universities	—		4,950	—	4,950	3.27
Other Nonprofit	—	—	1,350	1,250	2,600	1.72
Performer Dollars	16,400	108,450	22,050	4,700	151,600	100
Totals Percent	10.82	71.54	14.54	3.10		
			1992 BATTELLE FORECAST			
Federal Government	16,767	33,096	14,797	2,899	67,559	43.33
Industry	—	78,445	1,418	690	80,553	51.66
Colleges & Universities	—	—	4,951	—	4,951	3.18
Other Nonprofit	—	—	1,476	1,390	2,866	1.84
Performer Dollars	16,767	111,541	22,642	4,979	155,929	100
Totals Percent	10.75	71.53	14.52	3.19		
			PERCENTAGE INCREASES OVER 1991 ESTIMATES			
Federal Government	2.24	2.46	2.05	3.54	2.36	
Industry	—	3.01	13.44	6.15	3.21	
Colleges & Universities	—	—	0.02	—	0.02	
Other Nonprofit	—	—	9.33	11.20	10.23	
Performer Dollars	2.24	2.85	2.68	5.94	2.86	

forecast is shown in its historical setting in Table 1 and Figure 1.

In Table 2, we estimate the total calendar year 1992 R&D volume to be $155.9 billion, a 2.86 percent increase over the NSF estimates for 1991. It is expected that most of this increase will be absorbed by continued inflation (which we estimate to be 2.0 per cent from 1991 to 1992 for R&D).

In connection with this forecast, several important factors must be recognized. First, the total current-dollar projected increase includes an inflation factor that depends primarily on the inflation rate as it applies to R&D alone. This inflation factor is fundamentally different from that associated with the more familiar Consumer Price Index.

In addition, it is apparent that concerns over the federal debt, as well as expected changes in long-range priorities, have influenced the 1992 federal budget. Furthermore, since part of calendar year 1992 overlaps the next fiscal year (1993), the budget process throughout this current calendar year will have a continuing effect on total expenditures. Finally, industrial support for R&D will continue to be affected by previous years' sales and earnings, as well as concerns over business slowdowns, and should be expected to increase at only a small rate.

In using Table 2, the reader should keep clearly in mind all the distinctions made by the table headings. For instance, in the Industry *column*, we see that the total amount of R&D expected to be performed by industry in 1992 will be $111.5 billion. Of this, $33 billion will be funded by federal agencies, and almost $78.5 billion by industry. On the other hand, the Industry *row* indicates that industrial sources of funds are expected to support about $80.6 billion of R&D. Of this, $78.5 billion will be performed by industry, slightly over $1.4 billion by colleges and universities, and $690 million by other nonprofit organizations. Included within the Industry/Industry diagonal

Figure 1.
R&D Funding and Performance by Sector, 1974–1992

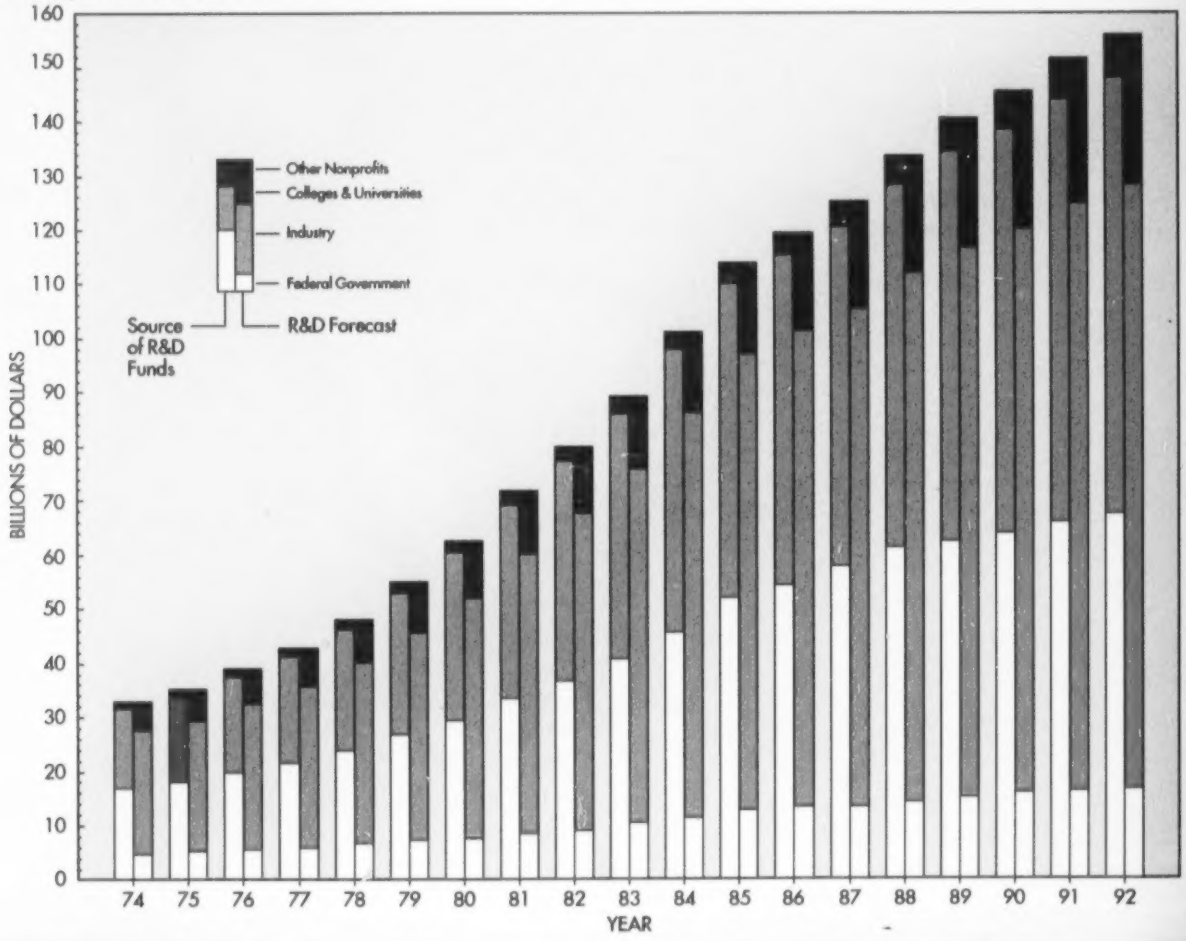
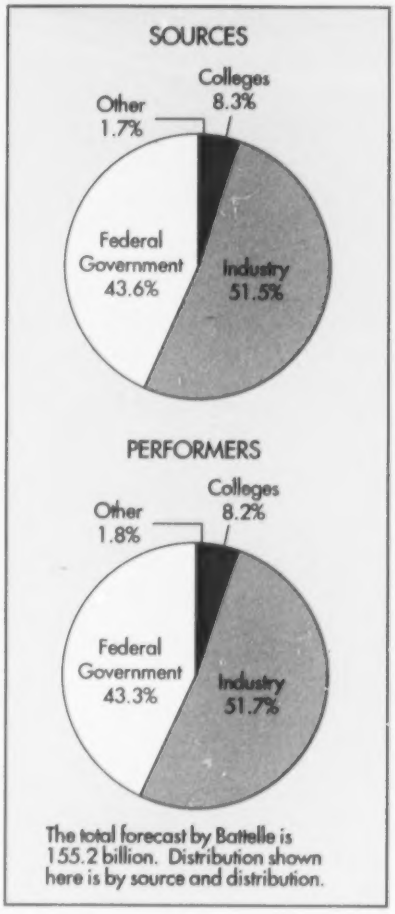


Figure 2.
R&D Expenditures in the U.S., Calendar Year 1992



The total forecast by Battelle is 155.2 billion. Distribution shown here is by source and distribution.

element is the R&D that is supported by one industrial organization and performed by another.

Continued inflation is expected to characterize 1992, although the rate, as experienced in R&D, has been declining for the past few years. The NSF estimated that current dollar total R&D activity rose by 4.2 percent from 1990 to 1992. We project a smaller increase, 2.86 percent, from 1991 to 1992. As will be shown in connection with the Cost of R&D Index, we expect a very modest increase in real R&D effort.

With respect to the composition of R&D activity, the expected pattern continues to be one of year-to-year stability or very slow change. Expected to provide the major impetus for change are defense-, science-, and technology-based problems; considerations of economic development and the federal budget deficit; and foreign competition. It is also important to note that the proportionate composition of both funding and performance will change very little. The federal government will account for 43.3 percent of the total funding, as compared with 51.7 percent from industrty. Industry will account for almost three-fourths of total performance. These two distributions for 1992 are summarized in Figure 2.

The Role of Federal Agencies

Although federal funding of R&D has lagged behind that of industry since 1980, the federal role and R&D budgets are major influences on total R&D spending. The federal role is important on three counts:

- The government provides approximately 43 percent of the total funding
- Government policies have an influence on industrial support of R&D
- Government policies have a strong influence on the interactions and cooperation between government and industry, as well as the interactions between other sectors.

The Federal Budget for Fiscal Year 1992, which began on October 1, 1991, reflects the major changes that have occurred in international affairs, and an appreciation of the role that science and technology play in economic strength. However, there are too many other pressures on the budget to permit massive infusions of funds for R&D. The huge deficits that derived from no-tax and military buildup initiatives and the bailouts of financial institutions have created a vise within which there is little room for maneuvering. Added to this are reduced revenues associated with business slowdowns. Perhaps the rosiest picture of the federal role in R&D is a greater sensitivity to the role of research in accomplishing national objectives: strong defense, a strong economy, and a safe environment.

Battelle projects that federal funding in calendar year 1992 will reach a level of $67.6 billion. This figure is based upon:

- Recent trends in federal budgeting, as reflected in NSF data series on R&D funding
- The relationship between federal funding and federal obligations
- The fact that three calendar quarters' funding will be determined by the FY 1992 appropriation
- The modification of selected mission agency activities.

The R&D-Minded Agencies

The big-money agencies for total 1992 federal R&D funding will include the Department of Defense (DoD), the Department of Health and Human Services (HHS), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE). Among the smaller agencies, the important suppliers of funds for extramural R&D include the NSF, the Department of Agriculture (DOA), the Environmental Protection Agency (EPA), and the National Institute of Standards and Technology (NIST)—an arm of the Department of Commerce. Estimated percentage shares for conducting R&D in the early proposed budgets for FY 1992, and comparative estimates of the FY 1991 plans and actual funding in FY 1990, are shown in Table 3.

This listing shows that DoD continues to dominate the federal scene, accounting for over half the R&D budget. The Big Four (DoD, HHS, NASA, and DOE) account for 90.6 percent of anticipated federal R&D expenditures, although distributions within these four have changed slightly over the recent past (and are expected to do so in the future). The next eight largest R&D-supporting agencies account for only 7 percent,

Table 3. Federal R&D Budget Authority*

	FY 1990 Actual	FY 1991 Estimate	FY 1992 Budget
DoD	56.98	53.66	54.29
HHS	12.84	13.89	13.19
NASA	10.70	11.94	12.56
DOE	10.59	10.81	10.58
NSF	2.60	2.82	2.97
DOA	1.86	2.03	1.84
EPA	0.64	0.66	0.65
NIST	0.20	0.26	0.27
All Other	3.59	3.93	3.66

* Distributions include funds for both conducting R&D and constructing R&D facilities.

and all others combined account for approximately 2.36 percent.

The federal R&D budget shows continued funding for the underpinning of science and technology that supports a broad range of both government and industrial needs. To be sure, one cannot always distinguish between these two users of research, for they tend to go hand-in-hand; a more efficient, productive industry strengthens the government's ability to maintain revenue flows that support other necessary government functions. Hence, federal initiatives cover a spectrum of needs and opportunities that includes advanced technologies in robotics, manufacturing, high performance computing, semiconductors, advanced imaging, and superconductivity. The extent to which all proposed programs are carried out will depend on the tradeoffs inherent in the process.

Of special concern in the total budget are the so-called pork-barrel projects for R&D performance and facilities. These types of projects have roused the ire of the scientific community, based largely on the lack of traditional peer review.

In viewing the estimated Budget Authority for different federal agencies, it is important to note that many agencies support research in areas not obviously connected with their formal designation. For example, the Department of Energy budget includes R&D support that relates to clean use of fuels (environmental protection), nuclear energy (for both defense and for power generation), and reactor design and safety (materials research). Similarly, the Department of Defense continues to support R&D that is related to weapons and delivery systems, yet this also encompasses materials development (composites and high-temperature alloys), materials and systems distribution (logistics software and transportation/packaging systems), specialized food and clothing development, and education/training programs. And the National Science Foundation covers an array of technical fields—from understanding the arctic environment to the development of new materials to high energy physics and biological processes.

The Applications of Federally Supported R&D

The preceding brief discussion of federally supported R&D programs—partially enumerating the federal role in conducting research and supporting the other institutions that perform research—has emphasized the programs that have specific application to rather well-defined objectives. In large part, these programs are for the direct and indirect support of functions under the purview of the federal government, either because of their direct application to functions that are specifically assigned to the government or because they represent necessary research that is too costly for other sources to support.

Over the past decade or more, efforts have been directed to promote broader use of technology supported and developed by the federal government, either in its own laboratories or in those of its contractors.

Over the past decade or more, efforts have been directed to promote broader use of technology supported and developed by the federal government, either in its own laboratories or in those of its contractors. Formalized technology transfer methods have been established to use existing government-developed technologies in applications that are far different from those originally proposed. The passage of the Stevenson-Wydler Act and subsequent Technology Transfer Acts have laid the groundwork for initiatives taken by the federal government, units of subfederal government, quasi-governmental agencies, and universities and private industry.

The initiatives supported by non-federal government or quasi-governmental organizations have responded to the *opportunity* that is provided by the federal laboratory system, the *mandate* that has been directed toward these laboratories, and, in some cases, the political *necessity* of proving the non-mission-specific utility of the laboratory. Regardless of the driving forces, the energies of all parties are being marshalled to promote economic development through the applications of technology.

The total R&D effort being pursued by federal, industrial, and intermediary institutions is one in which it is appropriate to look at a fourth category of research. To the traditional basic, applied, and development work, we add the concept of "translational research"—a term first coined in the 1991 Battelle R&D Forecast. At one end of the spectrum, translational research requires reverse engineering of finished products, the identification of applications of a technology where the requirements are not so stringent, and where simplified versions of the technology can be applied at far less cost. At the other end—and perhaps the easiest to undertake—translational research requires a knowledge of work in progress, the directions that it is taking, and the alternate

applications that can be commercialized before advanced government applications are realized.

Pioneering steps have been taken to facilitate the government/industry interface, to lower institutional barriers that exist, to provide incentives for researchers on both sides of the transfer process, to expedite licensing of technology, and even to make government facilities and personnel available for selected tasks. The states of New Mexico, Maryland, Ohio, and others have major initiatives to tap the federal resources and develop operations that will accelerate the commercialization of technology. We expect others will follow.

The access to federal laboratories is not a panacea. It is a significant step in the right direction. The effort by state or local governments is not significantly different from other initiatives that they have taken, including seed funds for technology development, the fostering of industry/university liaisons, and establishing other incentives and institutions. Perhaps a coupling of needs and actions on the part of the various levels of government will provide the type of environment within which existing industry can improve and new industry can be developed.

The Role of Industry

NSF data indicate that during the period 1980–1991, industrial support of R&D was greater than federal support. Battelle projects that industrial funding in 1992 will again exceed federal funding. As always, industry will be by far the predominant R&D performer.

For 1991, the NSF has estimated that industry provided 51.5 percent of total funding and performed over 71.5 percent of all R&D work (see Table 2). For 1992, Battelle's Forecast suggests only very small changes in these distributions.

The NSF data base indicates that industry has been the second fastest-growing sector. Table 4 compares sectoral growth rates for the nine-year interval 1982–1991. It is of particular interest that, as a source of funds, colleges and universities have grown significantly. The apparent rapid increase in university support during this period is partially due to the manner in which NSF collects and reports the R&D statistics. A significant amount of what is termed "university's own funds" is really the result of major industrial investments in large-scale programs.

Industrial funding is expected to rise from an NSF estimated level of almost $78.1 billion in 1991 to $80.6 billion in 1992. Industrial performance will rise from $108.5 billion to $111.5 billion. Note that the increases in both funding and performance by industry are smaller than in previous years, as was anticipated in the 1991 Battelle Forecast.

Industrial research, as applied to accomplishing industrial and governmental objectives, is both a means to an end and an end in itself. While the continuing profit motive in a competitive marketplace spurs R&D for individual industry's benefit, the industrial system also provides a mechanism to execute programs of high national priority.

The total R&D performed by industry can be divided into two major categories: that which is supported by industry itself (either in its own laboratories or by contracts with other industrial laboratories) and that which is supported by the federal government. In previous years, the Battelle Forecast has included a breakdown of the total R&D expected to be performed in each of 17 broad sectors and an estimate of the split between industrial and government funding of that research. This feature has been temporarily suspended, due to incomplete data, but may be reinstated in the future.

Table 4.
Sectoral Growth Rates in Funding and Performing R&D, 1982–1991

1982 = 100.0%

Sector	Source	Performer
Total United States	189.5	189.5
Federal Government	180.4	179.4
Industry	191.8	184.9
Colleges & Universities	286.0	225.0
Other Nonprofit	255.7	193.8

Source: Derived from Table 1.

Even if the data were available, the distribution between federal and industrial funds is somewhat misleading, because it does not address the more critical question of support for R&D among different lines of business. With R&D expenditures grouped according to major Standard Industrial Classification (SIC) codes, it is not possible to distinguish, for example, electronics research performed by a well-known electronics company from that performed by a subsidiary of a major company whose principal product line (and SIC code) falls into an entirely different category. Conversely, this determination does not isolate, for example, research in chemicals which is performed within the rubber or petroleum industries. More will be said of this in the section "The Need for Better Data."

An additional caveat should be noted relative to the ready availability of R&D data. A most convenient source of data on R&D investment is the annual *Business Week* Scoreboard, formerly published near the middle of the calendar year, but more recently in the autumn. The Scoreboard provides compilations of total R&D data for the major publicly held corporations, along with associated trends and ratios. While these data lend insights into broad patterns of support, they do not include information on privately held and/or small businesses. It is generally believed that these latter firms represent a most important element in the areas of applied research, commercialization, and new-job information.

In spite of the uncertainties attending the actual numbers that are reported

or projected, it is important to emphasize that the *trends* in R&D performance and the factors that influence these trends are more important than the more accurate figures.

Performance of R&D by industry will be financed either by the federal government or by industry itself (Table 2). Industrially funded work will be performed primarily either internally or contracted out to other industries. A small though increasing amount (approximately 2.6 percent) will be performed extramurally by universities and other nonprofit institutions. Overall, 70 percent of industrially performed R&D will be funded by industry, with the remainder being supported by the federal government.

The use of new technology can involve difficult choices: ... to adapt or not; to innovate or not; and the question of ... short-term losses vs. long-term profitability.

Factors Affecting Future Industrial Support

Over the past few years, industrial spending on R&D has increased significantly, although, as anticipated in recent years' Forecasts, the rate of increase in 1992 will be slightly lower. Spurts in industrial support, especially in the early- and mid-1980s, resulted from a healthier economy, increased sales and profits (both early indicators of R&D fund availability), relaxation of perceived barriers to cooperative research, and—to a small degree—the R&D tax credit enacted in 1981. However, other factors have influenced the near-future support for R&D. Several aspects of these factors must be emphasized, especially if we are to appreciate the lessons of history and plan for the future.

The U.S. R&D enterprise has, over the past 30 years and more, provided a wealth of knowledge related to the properties of materials and the devices and systems that can be developed from them. Almost every sector of the economy has developed technology that can affect all manner of processes and products. It is well within our grasp to improve health care; to access, process, and utilize growing volumes of information; to implement processes and products that would save resources; to improve the capacity for growing, processing, and distributing food products; to reduce pollution and utilize waste; and to bolster the overall physical infrastructure.

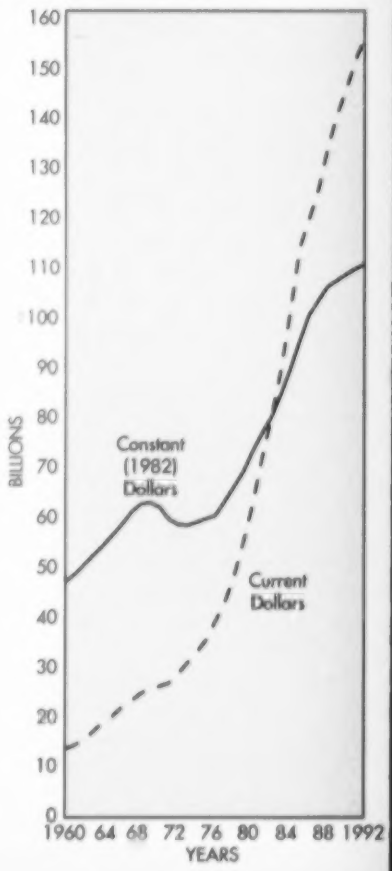
But the availability of technology and the fruits of R&D do not determine the extent to which technology is applied. The use of new technology can involve significant cost, and the issue reduces to a series of difficult choices: to adapt or not; the cost of innovating versus the cost of *not* innovating; and the question of potential short-term losses versus long-term profitability or even survival.

The recent emphasis on reindustrialization and competitiveness has driven selected firms to invest in modern operations and increased productivity. But the commitment to long-term growth and strength has been affected by a return to the short-term outlook that pervaded industrial management only a few years ago. The concepts of research and innovation are basically incompatible with the near-term profit objective. Thus, much effort has been directed toward alternative means of achieving this end, namely, the continued restructuring, buying of companies, and selling of non-revenue-producing components, and the art of the deal. Manipulation, rather than innovation, has become the route to selective success.

For the past four years, this Forecast has expected a slowdown in the rate of growth of R&D expenditures, perhaps even resulting in *decreases* in the constant dollar support of R&D. Such decreases certainly would not be unprecedented; a similar reduction occurred in the early- and mid-1970s (see Figure 3). If such a downturn occurs, it would probably not last as long as the earlier trough in real spending. Barring unforeseen major dislocations in the economy, a renewed perception of a federal government that is both friendly to business and understanding of the role of research will mostly reinstate confidence and the resultant support to R&D.

This is not to say that there will not be major changes in selected industries.

Figure 3.
Total R&D Expenditures, 1960–1991, in Current Dollars and Constant Dollars (1982 = 100%)



In particular, the changes in defense budgets will have a great impact on the aerospace industries and their network of suppliers. While the budgets for research will not suffer to the same extent as those for hardware procurement, the reduced profitability will have a direct impact on internal R&D support. Similarly, that portion of the electronics and telecommunications industries which provides direct support to the military will be affected by overall military procurement programs.

However, in the case of the latter, the explosion in telecommunications media and data transmission will provide continuing rationale for the support of further R&D.

Environmental factors—including both waste prevention and abatement and viewed as either aggressive or defensive research—will influence R&D spending in a broad number of industries. And the federal government emphasis on the so-called critical and emerging technologies will affect industrial decisions relative to long-term positioning and opportunities.

The further internationalization of markets will influence both the nature of R&D programs as well as the inter-institutional relations necessary to satisfy enhanced trade. A number of industries (most specifically those in the chemical and pharmaceutical industries) have taken significant steps to increase their offshore R&D activities, not so much to reduce costs, but to develop products and processes more in line with local regulations and habits. It is expected that an even greater degree of offshore R&D will characterize future industrial postures, especially among export-oriented firms. Conversely, it is expected that U.S.-based research institutions will benefit from greater support by foreign industry.

Finally, a major trend has emerged in industrially funded R&D: namely, to take a closer look at the menu of supported activities and assess the role of such programs in both present operations and strategic plans. The most basic level of this introspection is the comparison or benchmarking of detailed R&D expenditures, an activity in which Battelle has been engaged for quite some time.

There are, however, inherent problems in attempting to quantify the benefits of technology acquisition. To date, there is no known method for evaluating the output of R&D.

As industry (and even government) look toward their R&D investments, a greater emphasis has been placed on the concept of "intellectual assets." These consist of measuring the investment in R&D and other technology acquisition, and the expected value of the acquired knowledge. There are, however, inherent problems in attempting to quantify the benefits of technology acquisition. To date, there is no known method for evaluating the output of R&D.

One may approach the issue by analyzing the impact of past research, comparing present sales and income to past R&D directed toward the development of processes or products. Attempting to do so, however, presents serious problems of attribution, and may underestimate the extent to which present know-how has derived from a variety of former R&D activities.

Conversely, one may look at present R&D programs and make judgments regarding the manner in which the successful conduct and implementation of R&D will have a likely impact at some future date. This approach could conceivably provide a means for selecting among program or project alternatives.

In either case, the methodology to assess R&D impacts must be developed with a view toward the technological implications, the markets, and considerations of the management of R&D resources.

The Impacts of Technological Advance

In other sections of this Forecast, we have spoken of the fact that the U.S. R&D enterprise does not lack for the capacity to innovate, to discover, to improve, and to design new approaches toward the development of new products and processes. The argument has been raised that the U.S. lags behind other countries in expenditures on R&D as a percent of Gross National Product (GNP), and therefore we will fall behind. It has further been maintained that U.S. industry is categorically more concerned with short-term profits than with long-term stability or survivability. And finally it has been noted that, while we have significant strength in R&D capability in almost every area of science and technology, we lack either the will or the way to reduce R&D to practice.

Throughout this series of annual Forecasts, as well as other activities, Battelle has examined many of these issues and has learned, as many others have, that technologically sound innovations cannot be considered alone in the decision to implement technology. One must face not only the costs of implementation and the cost of *status quo*, but also consider the broad question of the impacts of innovation and implementation. These impacts may be felt within a single organization or within both a local and national economy.

It is thus incumbent upon industry and government alike to delve more deeply into the issues of technology assessment and impact, addressing such questions as the effects of materials or process substitution; the ripple factor as technical advances in one sector have economic impacts in

others; the needs for changes in the workforce; and the long-term planning required to accommodate the need for scientists, managers, technicians, and other support personnel. Technology-based industry is perhaps more vulnerable to manpower issues than most other sectors, for the elements of intensive and extensive training and education lie at the core of a rapidly changing industrial base. As a consequence, these industries have a considerable stake in education at all levels and in the support of programs that will eventually provide them with skilled personnel.

Considering the impacts of technological change does not imply that all potential problems should be examined before new research is put to practice; to do so would stifle growth, impair competitiveness, and have a detrimental effect on research itself. But to encourage a greater awareness of the impacts (positive and negative) of technical change will better prepare users of new technology to adopt and implement it and to avoid adverse effects.

... to encourage a greater awareness of the impacts (positive and negative) of technical change will better prepare users of new technology to adopt and implement it and to avoid adverse effects.

The Role of Academic and Other Nonprofit Institutions

Nonprofit institutions—colleges, universities, and other types—both fund their own research and conduct research funded by federal agencies and/or industrial firms. A significant portion of all basic research, as well as some of the longer-maturing applied research, is conducted in these sectors.

In 1960, the academic and other nonprofit institutions financed from their own resources (including endowments and direct state and local funds) approximately 2 percent of all R&D (see Table 1), while actually performing over 9.5 percent of the total. For 1992, Battelle forecasts that these same nonprofits will provide 5.0 percent of all funding and will perform 17.7 percent of the total (see Table 2). These percentages are slightly higher than the corresponding ratios for the 1991 NSF estimates.

The growth in nonprofit R&D performance has been accompanied by minor shifting within the nonprofit sector. In 1960, the academic community accounted for 55.4 percent of total nonprofit funding and performed 78.1 percent of the nonprofit total. For 1992, Battelle forecasts 63.3 percent and 82.0 percent, respectively. A significant portion of the increase in academic support and performance derives from the increase in major industrial support (directed endowments) associated with specialized areas of research such as electronics, artificial intelligence, and biological sciences.

There are two distinct groups of other nonprofit organizations. These are the foundations and associations which exist for various charitable and other purposes, and the nonprofit research centers which may or may not perform under contract. The first group funds a great deal of research, through grants and contracts, which go both to members of the academic community and to other nonprofit centers. The second group acts in three ways:

- A member may perform as a foundation
- It may fund its own research
- It may perform under contracts (with government, industry, or other nonprofits).

From 1965 to 1980 other nonprofit performance fluctuated slightly between 3.3 and 3.7 percent of total R&D. Since that time, this sector declined to less than 3 percent, reaching a minimum in 1988 and rising slowly since then. For 1992, Battelle estimates that the other nonprofit sector will comprise 3.2 percent of total R&D performance. Furthermore, we estimate that 51.5 percent of other nonprofit funding will go to colleges and universities, with the remainder being spent by the other nonprofit sector itself.

Total R&D performance in the other nonprofit sectors is not increasing as rapidly as in other performing sectors. However, this sector is composed of quite diverse constituent organizations. As performers of R&D, the establishments within this sector range from institutions such as Battelle (engaged in a spectrum of technology development, commercialization, and management programs) to small nonprofit firms that act as delivery mechanisms and research arms for federal, state, or local government agencies, especially for social programs. The activities of these latter types of organizations have been significantly reduced in recent years.

Finally, in addition to contracts or grants to support research on industrial problems (the industry funding of colleges and universities shown in Table 2), there is another form of support, not yet reported in detail by the NSF, that must be noted. This is the individual or collective industry/university arrangement which more nearly resembles directed endowments than either specific research contracts or a general gift. The large multiyear programmatic grants are then accounted for as college and university self-funding.

In recent years, there has been some reconsideration of this type of industrial support to the universities. Given constraints imposed on overall

R&D budgets, and pressing needs for more rapid turnaround of research into products and processes, large industry-sponsored university programs are coming under strict review. Curtailment of these programs, with a possible shift to short-term contracts or in-house projects, is a distinct possibility. The extent to which this occurs depends, in part, on the expansion of the federally supported special centers with their industrial "memberships."

The Cost of R&D Inputs

From an economic point of view, inflation can be defined as a general rise in the price of goods and services that is not offset by corresponding increases in quality. Most price considerations take place within the context of goods prices (i.e., the prices of tangible things). The tangibility of goods makes it possible both to measure quantity and to estimate, within reasonable limits, changes in quality. Thus, there usually is agreement as to whether or not costs are rising faster than output, or prices faster than quality, and there is general agreement that inflation is or is not occurring in the goods-related economy.

Services, on the other hand, are intangible. Therefore, there is usually greater difficulty achieving agreement that, in terms of any meaningful measure, the quantity or quality of service output is rising or falling. Thus, our only measure of output for many types of service is the total amount of money that we pay for them—and that is a function of price and quantity, with no account taken of quality.

R&D, by definition a part of the knowledge industry, is primarily a service activity, and we have no agreement as to what can be termed a unit of R&D output. Consequently, one cannot ascertain whether or not the price of R&D output is rising or falling. However, we can put a price on R&D inputs. For that reason, most discussions of the cost of R&D tend to be couched in those terms. Battelle has not yet given up hope of achieving a measurement of R&D output and from time to time has undertaken investigations that may lead to quantifying at least some kinds of R&D output. Nevertheless, such a measurement is not now available, and the discussion that follows must be in terms of input costs.

In viewing the costs of R&D performance, it is tempting to contrast the inflation in R&D with the commonly used Consumer Price Index (CPI)—the factor that provides a measure of general inflation—or to use the GNP deflator, as NSF does. To do so misses three basic points distinguishing R&D from the more general set of purchases.

First, the CPI is based upon a defined average marketbasket purchased for general consumption, and the GNP deflator covers a somewhat broader range. However, purchases by R&D performers are from a much more specialized collection of goods and services.

Second, researchers have a built-in bias for the acquisition and use of more sophisticated (and, hence, generally more expensive) materials, devices, and systems. Were it not for this fact of the research culture, technological advancement would not be so rapid.

Third, and perhaps most important, the very nature of research is such that problems researchers address are increasingly more difficult. The easy questions are always answered first, and the effort necessary to make incremental gains in the understanding and application of science and technology is ever increasing.

To offset these shortcomings, we define a Cost of Research Index which more nearly accounts for the specialized purchases that are required to perform the R&D function. The Cost of Research Index does not *always* exceed the GNP deflator or the CPI. While it is based on the average weighted expenditures of R&D dollars per R&D professional, the actual dollars support a broad range of technical support personnel, computer hardware and software acquisition and use, amortization of equipment, and all the overheads associated with the conduct of research. Thus, the Index is also related to the sophistication of support equipment and the total environment of the research laboratory. Furthermore, there is an expected difference in the Index as interpreted for basic and applied research, and for development. To date, no effort has been directed toward analyzing the distinction between these broad fields of research, and no detailed methodology has yet been devised for investigating the true costs of research in greater detail.

The Cost of R&D Index

In the absence of a measure of R&D output costs, many organizations, including the NSF, use the GNP deflator (from the national income and product accounts) as an indicator of changes in R&D costs. This index responds to the costs of both goods and services. R&D costs are made up primarily of service costs. Battelle, therefore, feels that the GNP deflators probably have misstated rates of inflation with respect to R&D.

The Battelle Cost of Research Index, displayed in Table 5, is based on two series regularly published by the NSF: (1) the R&D performance figures, by sectors, already discussed in connection with the Source/Performer Matrix (Table 2); and (2) estimates of the full-time equivalent numbers of R&D scientists and engineers employed by each performing sector. The ratio of costs to scientists/engineers for each sector provides the basis for the sectoral subseries, which are then weighted and combined into the all-sector average. We expect the cost of R&D to increase by about 2.0 percent

Table 5.
Battelle Cost of Research Index* by Performing Sectors, Calendar Years 1960–1992 (1982 = 100)

Year	Total U.S.	Performing Sectors: Federal Government	Industry	Colleges & Universities	Other Nonprofit
1960	28.68	23.03	30.97	20.42	35.28
1961	29.42	24.07	31.32	23.26	36.21
1962	30.47	25.64	31.99	26.02	37.50
1963	32.51	26.48	34.29	28.89	37.04
1964	34.74	31.57	35.81	32.21	36.50
1965	35.51	32.85	36.47	33.10	37.09
1966	37.29	33.02	38.69	34.60	39.24
1967	37.98	33.52	39.35	35.78	39.93
1968	39.28	33.68	40.88	37.96	39.07
1969	40.75	34.58	42.53	37.71	45.69
1970	42.19	39.67	43.09	39.22	48.11
1971	44.81	43.43	45.77	41.12	47.01
1972	48.68	49.07	49.48	44.14	48.62
1973	52.65	53.71	53.04	49.96	50.23
1974	55.73	55.29	56.68	51.06	56.29
1975	59.01	60.18	59.54	54.35	61.77
1976	64.72	71.04	64.73	58.38	65.19
1977	67.76	71.75	67.88	62.88	69.36
1978	72.84	78.28	72.03	71.29	74.46
1979	79.50	84.83	78.31	80.45	80.73
1980	85.51	85.49	84.97	88.10	87.05
1981	93.57	93.42	93.05	96.37	94.85
1982	100.00	100.00	100.00	100.00	100.00
1983	105.50	113.31	103.94	107.31	108.30
1984	112.88	122.31	111.07	115.52	115.18
1985	119.48	135.09	116.67	123.58	123.01
1986	119.02	140.35	114.99	127.50	120.32
1987	121.40	141.32	117.43	131.27	121.06
1988	125.96	142.46	122.34	135.22	126.36
1989	130.84	149.25	126.20	141.94	142.25
1990	133.95	157.02	128.64	143.63	152.30
1991	138.20	158.30	133.08	147.26	163.53
1992	140.97	160.67	136.13	147.33	173.24

Source: Estimated by Battelle from NSF and Battelle data.
*Costs of performing R&D per scientist/engineer (full-time equivalence).

between the estimated 1991 level (138.20) and the forecast level for 1992 (140.97), with the estimates stated in terms of the 1982 base.

Trends in Real R&D Effort, by Sectors

If we take total expenditures and sector performance figures from Tables 1 and 2 and deflate them to constant 1982 dollars with the corresponding index numbers from Table 5, we can make parallel comparisons for each of the four performing sectors. These are shown in Table 6 and graphed in Figures 3 and 4.

In current (undeflated) dollars, total U.S. R&D expenditures have risen in every year of the period, even though the rate of increase fell sharply between 1969 and 1971. But the deflated (real effort) series before 1978 reached its peak in 1969, declined between 1969 and 1973, and leveled out until 1977, when it exceeded $62 billion for the first time in eight years. We expect real R&D effort in 1992 to increase by less than 1 percent over 1991 and to reach a level that is 75.8 percent above its 1969 peak.

When we examine the performing sectors, we find the recent upward shift of real R&D activity results from the behavior of the private sectors. The downturn or flat behavior in real expenditures that began after 1968–69 is clearly reflected by every sector. However, deviations in sector behavior emerged later, especially since 1975. In government, the real performance series has recovered only slowly from its 1976 minimum and, in 1992, is expected to finally exceed its previous (1968) peak.

In the private sectors, industry reached its real low in 1972 and has since risen by over 107 percent to its highest recorded value. The academic community reached a low in 1973. Since then, its real performance has also risen by 107 percent and now stands well above the 1968 value. Other nonprofit institutions real performance declined slightly from 1968 through 1970. Since that time, it has risen by 50.9 percent.

Finally, we turn to the data of Table 6 and the curves of Figures 3 and 4 to see the dramatic differences in the R&D trends among the four performing sectors. Since the lull of the early 1970s, industrial performance, funded by both government and industry, has been largely responsible for the real growth within the R&D enterprise. The behavior exhibited in Figures 3 and 4 suggests that the real growth in R&D (and the economic development and expansion that result from it) has come from applied research supported and performed by private industry. However, applied research and development must rest on, and evolve from, the basic research foundation—an activity that is primarily supported by the federal government (almost 65 percent).

Over the past few years, federal support had tended to shift more toward development and less toward basic and applied research, although this trend appears to be reversing. The federal government is still the major supporter of basic research, and trends in the federal budget indicate that this support will continue to be strong. In addition, there is a

Table 6.
Current and Constant Dollar (1982 = 100) R&D Expenditures in the U.S., 1960–1992, by Performers (All Amounts in Millions of Dollars)

	Total U.S.		Federal Government		Industry		Colleges and Universities		Other Nonprofits	
Year	Current	Constant	Current	Constant	Current	Constant	Current	Constant	Current	Constant
1960	13,523	47,156	1,726	7,496	10,509	33,935	1,006	4,926	282	799
1961	14,316	48,654	1,874	7,785	10,908	34,828	1,173	5,044	361	997
1962	15,394	50,516	2,098	8,181	11,464	35,833	1,374	5,280	458	1,221
1963	17,059	52,476	2,279	8,608	12,630	36,838	1,611	5,576	539	1,455
1964	18,854	54,274	2,838	8,989	13,512	37,731	1,904	5,911	600	1,644
1965	20,044	56,448	3,093	9,415	14,185	38,892	2,103	6,354	663	1,787
1966	21,846	58,583	3,220	9,750	15,548	40,187	2,345	6,778	733	1,868
1967	23,146	60,951	3,396	10,131	16,385	41,638	2,594	7,251	771	1,931
1968	24,605	62,646	3,494	10,375	17,429	42,631	2,868	7,556	814	2,084
1969	25,631	62,901	3,503	10,131	18,308	43,044	2,950	7,822	870	1,904
1970	26,134	61,947	4,079	10,284	18,067	41,928	3,072	7,832	916	1,904
1971	26,676	59,527	4,228	9,735	18,320	40,030	3,216	7,822	912	1,940
1972	28,477	58,493	4,590	9,354	19,552	39,517	3,383	7,664	952	1,958
1973	30,718	58,342	4,762	8,867	21,249	40,064	3,701	7,408	1,006	2,003
1974	32,864	58,966	4,911	8,882	22,887	40,376	3,888	7,615	1,178	2,093
1975	35,213	59,673	5,354	8,897	24,187	40,622	4,396	8,088	1,276	2,066
1976	39,019	60,289	5,769	8,120	26,997	41,705	4,877	8,354	1,376	2,111
1977	42,783	63,141	6,012	8,379	29,825	43,937	5,451	8,669	1,495	2,156
1978	48,128	66,077	6,810	8,699	33,304	46,237	6,342	8,896	1,672	2,245
1979	54,953	69,123	7,418	8,745	38,226	48,815	7,315	9,093	1,994	2,470
1980	62,610	73,221	7,632	8,928	44,505	52,376	8,323	9,447	2,150	2,470
1981	71,868	76,809	8,426	9,019	51,810	55,681	9,332	9,684	2,300	2,425
1982	80,018	80,018	9,141	9,141	58,650	58,650	9,802	9,802	2,425	2,425
1983	89,139	84,491	10,582	9,339	65,268	62,791	10,614	9,891	2,675	2,470
1984	101,139	89,598	11,572	9,461	74,800	67,346	11,767	10,186	3,000	2,605
1985	113,818	92,257	12,945	9,583	84,239	72,202	13,209	10,689	3,425	2,784
1986	119,529	100,429	13,535	9,644	87,823	76,377	14,821	11,624	3,350	2,784
1987	125,352	103,258	13,413	9,491	92,155	78,475	16,359	12,462	3,425	2,829
1988	133,741	106,179	14,281	10,025	97,889	80,016	17,996	13,309	3,575	2,829
1989	140,486	107,376	15,121	10,131	101,599	80,507	19,716	13,890	4,050	2,847
1990	145,450	108,589	16,100	10,253	104,200	80,998	20,800	14,481	4,350	2,856
1991	151,600	109,697	16,400	10,360	108,450	81,489	22,050	14,974	4,700	2,874
1992	155,929	110,614	16,767	10,436	111,541	81,936	22,642	15,368	4,979	2,874

Source: Current dollar figures from Tables 1 and 2, deflated in terms of Battelle Cost of Research Index of Table 5.

continuation of basic research support by industry. Yet, the volatility of factors that influence industrial R&D budgets—sales, profits, and cash flow—precludes the stability needed for long-term planning. Policy- and budget-makers in all funding sectors should note very carefully the trends in basic research, since the conduct of such research forms the basis for future economic vitality and competitiveness.

A Look Toward 1993 and Beyond

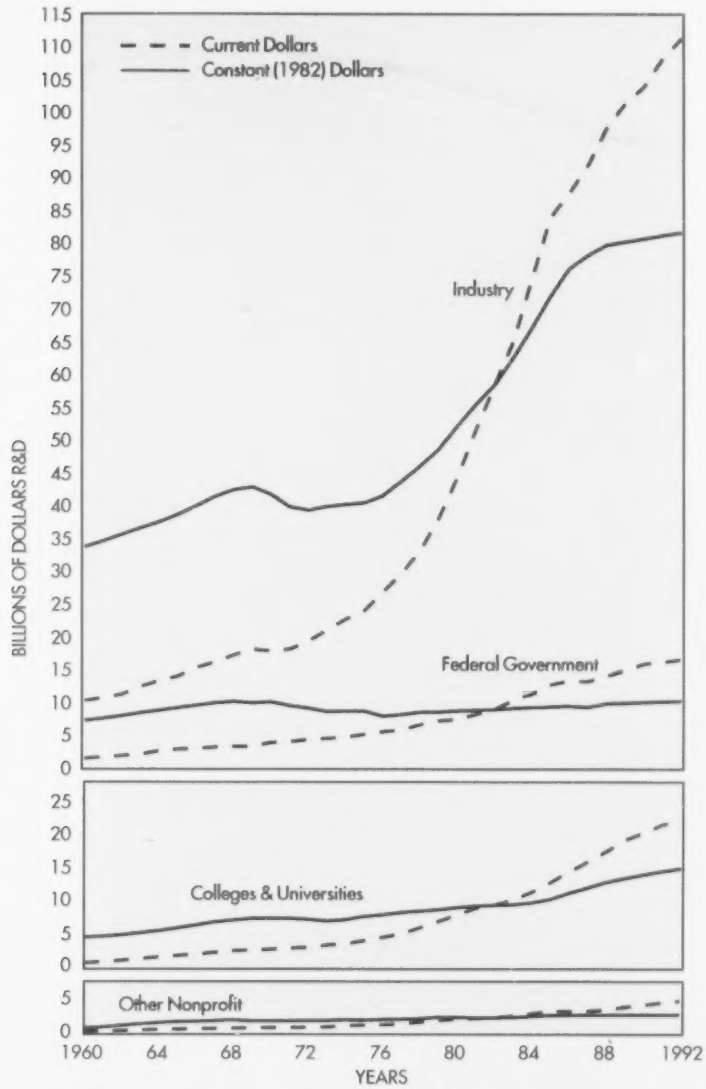
While former issues of the Battelle Forecast and Analysis (through the 1983 edition) were confined to considerations of the forthcoming year only, well-established commitments by both the federal government and industry now permit a longer look at the R&D forecast. 1992 is not expected to be a banner year for R&D; the forces that have led to a slowdown in the rate of increase of funding will either continue or, at best, slowly begin a reversal. Whether the picture becomes brighter in the near future will depend on a number of factors—the most important being the interactive effects of business growth and reduced deficits.

Due to the inertia of R&D funding and performance, dramatic changes are not readily accommodated. To be sure, it is simpler to absorb the problems associated with downturns in funding than to gear up for significant new starts. Hence, even in the unlikely event of a major economic recovery—with the promise of substantial increases in funds that are available for R&D—and an equally implausible resolution of the federal budget problems, it will take some time for the R&D enterprise to experience a growth similar to that of the early- to mid-1980s.

Basically three scenarios will influence R&D funding over the next few years:

(1) Continuation of the present economic sluggishness, with the result that real R&D spending will decrease;

Figure 4.
R&D Expenditures by Sectors, 1960–1992, in Current Dollars and Constant Dollars (1982 = 100%)



(2) Slow recovery, with small increases in real R&D support, largely driven by industrial initiatives; or

(3) More rapid recovery, assisted by government spending and a reduction in the budget deficit (fueled by increased revenues).

Given these three scenarios, we estimate funding and performance (in constant 1991 dollars) for 1993 in Table 7.

Considerations Relative to Future R&D Support

The trends which pointed to a slowdown in the rate of growth, noted in the last three Forecasts, are expected to continue, although for different reasons. The changing international scene, with the so-called peace dividend playing a role, suggests that R&D funding should begin to grow in real terms. On the other hand, the federal deficit continues to take its toll. It is apparent that the provisions of the highly touted Gramm-Rudman-Hollings Act have been cast aside, and—especially in an election year—no discipline will be exerted by either the Administration or the Congress. While R&D will continue to receive moderately good support, not all of the promise will be maintained in the near future.

Industrial R&D growth will continue to respond to foreign competition, and will be influenced (positively) by the opening of new markets, especially in Eastern Europe. Furthermore, tax credits for R&D will influence spending, albeit more as a perturbation rather than a significant driving force. Because of lag time between increased sales or profits and R&D expenditures, one may not look for significant increases in industrial R&D until at least 1994.

An additional bright light as regards both government and industrial funding, as suggested earlier, is the acceleration of interest in technology transfer and adaptation as more federal laboratories take a stronger interest in promoting their own technical capabilities. Additional funding from providers and users—perhaps through intermediary channels—will likely be forthcoming.

Increases in university self-funding and performance in the near future continue to be, in part, a consequence of increased industrial actions of the recent past. However, there is potential disenchantment with such programs, and industrial partnerships may see a near-term decline. This will certainly result if: (1) the universities feel an encroachment upon their independence and sovereignty; (2) supporting industries are unable or unwilling to reduce research to applications and profit; or (3) industrial sales and profits will not support future endowed investments of this type. If any of these conditions comes to pass—and the next two to three years is the critical period—the industry/academia honeymoon may be merely an anomaly in the broader picture of long-term relations.

Table 7.
Estimated R&D Funding and Performance for 1993

	Scenario 1	Scenario 2	Scenario 3
Funding*			
Federal Government	67,172	68,580	70,750
Industry	81,210	82,260	84,350
Colleges & Universities	5,000	5,100	5,400
Other Nonprofit	3,000	3,100	3,130
Funding Totals	156,382	159,040	163,630
Performance*			
Federal Government	16,600	17,000	17,200
Industry	112,000	113,800	117,500
Colleges & Universities	22,680	23,040	23,600
Other Nonprofit	5,102	5,200	5,330
Funding Totals	156,382	159,040	163,630

*Millions 1991 dollars.

The trends noted in this year's forecast are not optimistic for the support of research in the near future. However, even if there were to be flat growth or decrease in R&D, the bright note is that this feature would not be expected to last nearly as long as that of the early 1970s. In that case, about eight years elapsed, on average, for the R&D levels to reach their previous highs. Unless something completely unexpected occurs, such as an exacerbated worldwide economic depression, the turnaround time should be substantially less, perhaps on the order of four years.

We may be presently encountering a few speed bumps on an otherwise unobstructed road.

The Need for Better Data

Were it not for competition on either a domestic or international scale, neither industry nor government would have much need for statistics on the support and performance of research and development. However, such competition is very real.

- Companies need to know how their efforts in R&D compare with others in similar marketplaces, how they are positioned to develop or acquire new technology in various lines of business, and if they will be able to respond to new opportunities.
- Government needs information about its support of R&D in pursuing its missions, or in positioning its industry to be competitive on a world scale.
- Universities and other non-profit R&D performers rely upon R&D statistics as a means to define curricula and research agendas.
- R&D planners at all levels need information on the relationships between the supporters and the performers of R&D.

Industrial R&D Detail

Earlier, we alluded to difficulties associated with analyzing industrial expenditures on R&D. The most readily available statistics—including those from the NSF surveys, the former DRI/McGraw-Hill surveys, and the SEC 10-K forms—make no distinctions among R&D commitments to various lines of business. Chemical research conducted by companies in the petroleum industry is not reflected in the statistics that refer to the broad industrial class of chemicals. Conversely, petroleum-related research conducted by the chemical companies is not included in figures that presumably represent petroleum research. As automotive companies devote significant funds to electronics and computer research, as tobacco companies acquire food processing and distribution concerns, and as both inter- and intra-industry mergers or acquisitions occur, there is continued erosion of our understanding of the distribution of R&D and the factors that influence trends.

Industry R&D managers have long needed more detailed information as it applies to their own R&D commitments, the distribution of limited resources (both dollars and personnel), and the optimization of the R&D operation. Without detailed information regarding the trends among critical ratios in the various lines of business for which an R&D manager is responsible, the decision-making process is impaired.

As a result of this need, and recognizing the risks involved with individual attempts to gather data, Battelle has initiated projects that provide the type of analyses and comparative information that are an integral part of the resource management process. Starting with the petroleum industry, and expanding to others, Battelle developed a procedure that addresses basic information needs, while avoiding the complications faced by individual companies.

These analytical procedures assist individual companies in improving their own competitive position in setting internal R&D policy, and in providing the input necessary to integrate R&D with the larger strategic planning and analysis process. Expanding this approach to other industries, including chemicals, automotive, paper and wood products, ceramics, pharmaceuticals, information processing (including hardware, software, peripherals, etc.), composites, polymers, and the so-called critical and emerging technologies,

will provide a better picture of the trends within R&D and a more nearly accurate accounting of the distribution of R&D effort.

International Comparability

While intra-industry comparability is useful for defining competitive positions and developing R&D strategies, international comparability is often sought to determine whether total U.S. efforts will result in maintaining a strong position for future trade and expanded markets. Broad statistics on total R&D, selected comparisons on R&D in various functional areas, and estimates of R&D as a ratio to GNP or equivalent are usually available through the National Science Foundation, the Organization for Economic Cooperation and Development, and other agencies.

The numbers that describe total U.S. and foreign R&D efforts are instructive to the extent that they permit general assessment of the relative commitment to R&D and some insights into the distribution of total R&D resources among various functional areas. However, these data are of relatively little value when attempting to formulate policies or approaches that must be translated into specific actions. The total value of R&D investment provides no more detail on the national scale than does the total value of R&D as reflected in the industrial R&D quoted in the sources cited in the previous section. That is, total values tell you everything while telling you nothing. They provide gross statements relative to national expenditures, but say nothing about the structure of the R&D effort, the relationships among supporting and performing sectors, and the manner in which these relationships change as a result of policy actions.

In its simplest structure, the U.S. data, as presented by NSF and Battelle, consider the four major source/performer sectors of federal government, industry, colleges and universities, and other nonprofit organizations. However, the actual support and performance of R&D encompass other relationships, some of which are very important in terms of regional economic growth and the promotion of developer/user interfaces. There are no known continuous sources of information relative to R&D at the more disaggregated scale; hence, there is little or no information available upon which new policies and approaches can be defined. The paucity of data should be corrected if sensible initiatives are to be undertaken.

While not all the detail available in other countries' data may be necessary for the U.S. setting, it is obvious that U.S. statistics provide only limited value relative to international policy development. As competitiveness continues to be an issue in political circles, industrial policy, and trade discussions, and as concern for long-term economic strength transcends mere political expediency, we need an improved understanding of the relative position of the U.S. R&D enterprise. Then we might be assured that the policy debate could take place in an environment of knowledge.

TECHNICAL APPENDIX

NSF DEFINITIONS OF RESEARCH AND DEVELOPMENT

Many activities, from one viewpoint or another, may be termed "research and development." The National Science Foundation (NSF*) has, since its inception, been concerned with both the definition and the measurement of R&D. To paraphrase the most recent NSF definitions:

Research and development ... consist of basic and applied research in the sciences (including medical sciences) and in engineering and activities in development.

Research, which encompasses both basic and applied, is systematic, intensive study directed toward fuller scientific knowledge of the subject studied.

Basic research. For three of the sectors—federal government, universities and colleges, and other nonprofit institutions—the definition of basic research stresses that it is directed toward increases of knowledge in science with ... a fuller knowledge of understanding of the subject under study, rather than a practical application thereof. To take account of an individual industrial company's commercial goals, the definition for the industry sector is modified to indicate that basic research projects represent ... original investigations for the advancement of scientific knowledge ... which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company.

Applied Research. Following is the core definition in the NSF questionnaire sent to the universities and colleges. Applied research is directed toward practical application of knowledge. Here again, the definition for the industry survey takes account of the characteristics of industrial organizations. It covers research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to either products or processes. By this definition, applied research in industry differs from basic research chiefly in terms of objectives of the reporting company.

Development. The NSF survey concept of development may be summarized as the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes.

* National Science Foundation, *National Patterns of R&D Resources*. 1989. NSF 89—308, p. 33.

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